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OVERVIEW OF THE INTEGRATED HIGH PAYOFF ROCKET PROPULSION TECHNOLOGY (IHPRPT) PROGRAM

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ABSTRACT

The Integrated High Payoff Rocket Propulsion Technology Program (IHPRPT) is a structured Government and Industry program to improve U.S. rocket propulsion systems. The program is technology driven, goal oriented, and application focused. Integration of the technologies developed by the IHPRPT program is accomplished through key demonstrations. These demonstrators are used to verify compliance with goals. The achievement of the IHPRPT goals and the transition to operational systems provide significant payoff as well as a high return on investment.

The IHPRPT program is being conducted as a fully coordinated, but not joint, effort. Each agency and Department of Defense component is responsible for funding and managing their respective portions of the effort. The effort is headed by the IHPRPT Steering Committee, which has representatives from each participating agency and service.

Industry plays an active role in the program through an involvement in planning, participation at Steering Committee meetings, conducting of technology programs, identification of commercial transition opportunities, advocacy of the program, and teaming.

INTRODUCTION

The IHPRPT program initiated its program execution phase in 1996 to focus and direct rocket propulsion technology development and demonstration within the Department of Defense (DOD), NASA, and rocket propulsion industry. The program vision is to double U.S. rocket propulsion capability (cost and performance) by 2010. Government and industry worked together to develop *firm, challenging*, but *attainable* propulsion technology goals that are *time-phased* and *measurable*. Attainment of the goals and subsequent incorporation of technologies into existing and future systems will enable the U.S. to reduce launch costs and improve performance and reliability[i].

With this common vision established for boost, orbit transfer, spacecraft, and tactical propulsion, both government and industry directed their resources toward the pursuit of these goals. The stability of IHPRPT funding from the government and clear goals encouraged industry to align their technology development plans with IHPRPT and invest their independent research and development (IR&D) pursuing the goals.

This paper will describe the IHPRPT goals and the payoffs for each of the mission application areas related to space, and discuss some of the key transition opportunities for the technologies. The IHPRPT program structure and processes will also be described along with a case study of how IHPRPT functions with solid propulsion technology.

GOALS

The IHPRPT goals for Boost and Orbit Transfer and Spacecraft propulsion are shown in Table 1. The goals are measured relative to 1993 baseline technology. The goals represent percentage improvements over documented baselines. Baseline systems have been identified for each class of propulsion system being pursued. Baselines do not necessarily represent the specific production systems if the state of the art was deemed to be significantly more advanced than a previously fielded system. These goals represent a coordinated commitment and vision to the United States Government and industry for the investment of its resources. The level of coordination, planning, and program execution has set IHPRPT apart as model program for science and technology development.

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Table 1. IHPRPT Goals for Boost and Orbit Transfer and Spacecraft Propulsion

Boost and Orbit Transfer Propulsion	**2000**	**2005**	**2010**
Reduce Stage Failure Rate	25%	50%	75%
Improve Mass Fraction (Solids)	15%	25%	35%
Improve Isp (Solids)	2%	4%	8%
Improve Isp (sec) (Liquids)	14	21	26
Reduce Hardware Cost	15%	25%	35%
Reduce Support Costs	15%	25%	35%
Improve Thrust to Weight (Liquids)	30%	60%	100%
Mean Time Between Removal (Mission Life: Reusable)	20	40	100
Spacecraft Propulsion			
Improve I_{stot}/M_{wet} (Electrostatic/Electromagnetic)	20%/200%	35%/500%	75%/1250%
Improve I_{sp} (Bipropellant/Solar Thermal)	5%/10%	10%/15%	20%/20%
Improve Density: I_{sp} (Monopropellant)	30%	50%	70%
Improve Mass Fraction (Solar Thermal)	15%	25%	35%

The government and industry met numerous times to develop the goals for each mission application area. They were developed in keeping with the overall goal of doubling propulsion capability. By design, the goals were required to be propulsion system specific parameters to appropriately measure propulsion system technology advancement.

PAYOFFS

Payoffs from meeting the IHPRPT goals for Boost and Orbit transfer are shown in Figure 1. IHPRPT payoffs can take a variety of forms such as reducing the hardware and support costs and/or increasing the payload capability and/or reducing the size of the propulsion system for the same performance level. In the case of Boost and Orbit Transfer payoffs, shown in Figure 1, there is a cost benefit of 33% (both hardware and support costs are included). For the same size vehicle there is a payload capability increase with expendable launch vehicles (ELVs) of 22%. These two factors work together to lower the cost per pound of payload to orbit by more than 50% (more payload for less cost).

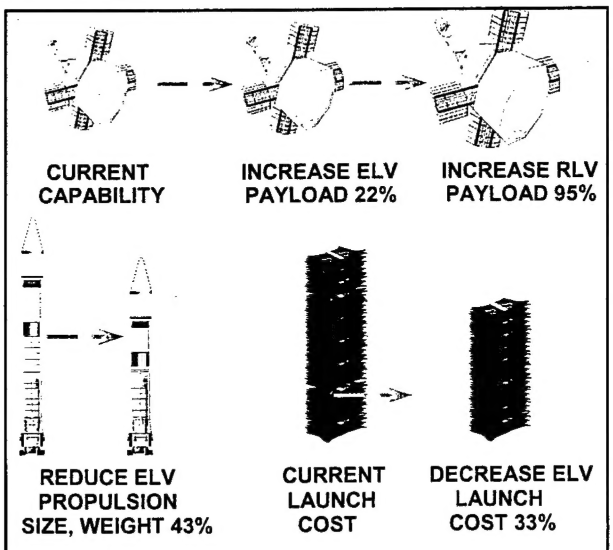


Figure 1. IHPRPT Boost and Orbit Transfer Payoff

Furthermore, for a "clean sheet" design, a smaller launch vehicle can be used that incorporates IHPRPT technology to deliver the same size payload. A smaller launch vehicle will have correspondingly lower costs for hardware and support.

The payoffs for spacecraft propulsion are shown in Figure 2. In this case, the payoffs are singular in nature. Either the life of a satellite is extended 45%, the size of the satellite is increased 30%, or the repositioning capability is increased 500%. It is calculated that the cost savings associated with these payoffs is $240M over the life of a satellite.

DEMONSTRATORS AND TRANSITION OPPORTUNITIES

Demonstrator projects are planned, under way, or have been completed in Boost and Orbit Transfer and Spacecraft propulsion in the following areas:

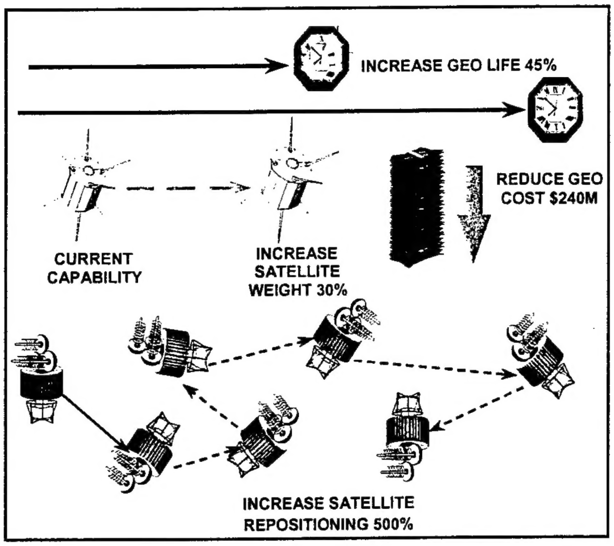


Figure 2. IHPRPT Spacecraft Propulsion Payoff

- ♦ Cryogenic Boost: both primary and upper stage propulsion
- ♦ Solid Boost: both Boost and Orbit Transfer Stages
- ♦ Hydrocarbon Boost (study)
- ♦ Solar Thermal Propulsion
- ♦ Electric Propulsion

Transition opportunities include Evolved Expendable Launch Vehicle (EELV) upgrades, Reusable Solid Rocket Motor (RSRM) upgrades for the space shuttle, small launch vehicles (Athena, Taurus, Air Launch, etc.), Reusable Launch Vehicles (RLVs), Solar Orbit Transfer Vehicle, and various other spacecraft.

IHPRPT PROGRAM APPROACH, ORGANIZATION AND MANAGEMENT[ii]

The IHPRPT program is organized into three *mission application areas* with demonstrators defined in each area:

- ♦ Boost and Orbit Transfer
- ♦ Spacecraft
- ♦ Tactical (not discussed in this paper)

Within each of the above mission application areas there are five *technology areas*: Propellants, Propellant Management Devices, Combustion and Energy Conversion Devices, Controls, and Demonstrators.

- ♦ The Propellant area includes solids (including liner), liquids, hybrids, and gels.
- ♦ The Propellant Management Device (PMD) area includes insulated cases, tanks, feed systems, bladders, turbomachinery, thermal protection systems, and pressurization systems.
- ♦ The Combustion and Energy Conversion Device (C&ECD) area includes nozzles, gas generators, preburners, injectors, igniters, and combustion chambers.
- ♦ The controls area includes actuators, controllers, ordnance devices, valves, and health monitoring systems.
- ♦ The Demonstrator area addresses component technology integration and scale-up issues. This test, or set of tests, is used to accumulate data for comparison to the baselines. With this comparison, progress toward goal achievement is determined.

Specific *technical objectives* are developed for each of the supporting technology areas to guide individual projects. The technical objectives are targets (such as component weight reduction, density increase in propellant, etc.) that each supporting technology must meet in order to measurably contribute to the overall IHPRPT goals for that mission application area. The objectives must result in a quantified improvement in the state of the art by necessarily satisfying the goals. This must be achieved by the accomplishment of specific technology projects, and must have a specific date by which it will be met.

From the technical objectives, *technical challenges* are identified. A technical challenge, in IHPRPT terminology, answers the question, "Why can't we accomplish the objective today?" Technical challenges are the most fundamental, scientific problem that must be overcome to meet the objective.

Once goals, technical objectives, and technical challenges have been identified, the *approach* is developed to overcome the technical challenges in order to meet the objectives and contribute to the goals.

The IHPRPT program uses an approach referred to as GOTCHA (Goals, Objectives, Technical Challenges, and Approach) to

communicate the plans that will enable goal achievement.

THE STEERING COMMITTEE

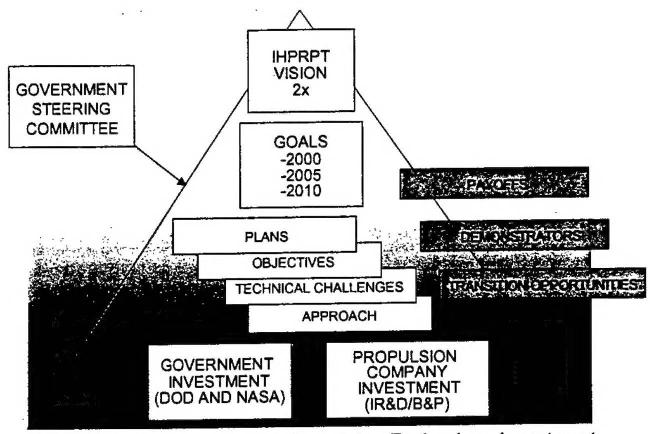
The IHPRPT Steering Committee, whose members represent each participating agency and service, heads the program organizational structure. This committee is co-chaired by the Office of the Undersecretary of Defense staff specialist for Space and a NASA representative. This committee meets bi-annually and provides guidance to the five technology planning groups. These planning groups are composed of senior science/engineering specialists from each participating agency and service, and are continually engaged in maintaining and updating detailed government long-range plans.

Each of the propulsion companies participating in the IHPRPT program has also developed, and maintains, its own long-range company plan and business strategy to achieve the goals of the program. These company plans are updated regularly, and formally coordinated with the government participants at least bi-annually.

The most important task for the management of the IHPRPT program has been to establish a dedicated and farsighted technical community across government and industry in order to provide an environment in which full coordination and long-range planning, technology execution, and accountability can be realized. This environment is being provided through the Steering Committee meetings. The meetings are structured and scheduled to provide reporting on key elements of the program on a timely basis. The meetings include participation by both government and industry. The committee is also responsible for establishing relationships with other federal agency performing related and/or supportive technologies.

THE IHPRPT PROCESS INTEGRATES WITH LONG-RANGE PLANS

As discussed previously, the IHPRPT program began by establishing baselines and goals relative to those baselines. Based on the goals, conceptual propulsion system designs for each class of demonstrator and phase were developed with allocated requirements for all the necessary components. These component requirements are termed technical objectives within each component technology area (Propellant, PMD, C&ECD, Controls). Technical approaches are developed and programs are conducted to meet the objectives. Demonstrators are defined and tested that show compliance with the goals. Once demonstrated, the technology is available to the user community. Figure 3 shows a summary of the major components of the IHPRPT approach. Figure 4 shows how the process integrates with planning activities for space launch at DOD, NASA, and industry. The planning process is continuous.



Basis for Government Rocket Propulsion Technology Investment

Figure 3. The IHPRPT Process

The industry just recently updated its Advanced Rocket Propulsion Plan (ARPP). These plans circulate and are briefed to various DOD and NASA parties involved in the planning process. There is significant interaction between IHPRPT planning and government users (DOD and NASA planning processes). This interaction feeds the creation of the IHRPT Government Rocket Propulsion Plan (GRPP), DOD Planning Documents, NASA Center Implementation Plans, and Industry Long-Range Plans. These plans are then checked for consistency with the ARPP, and the process continues.

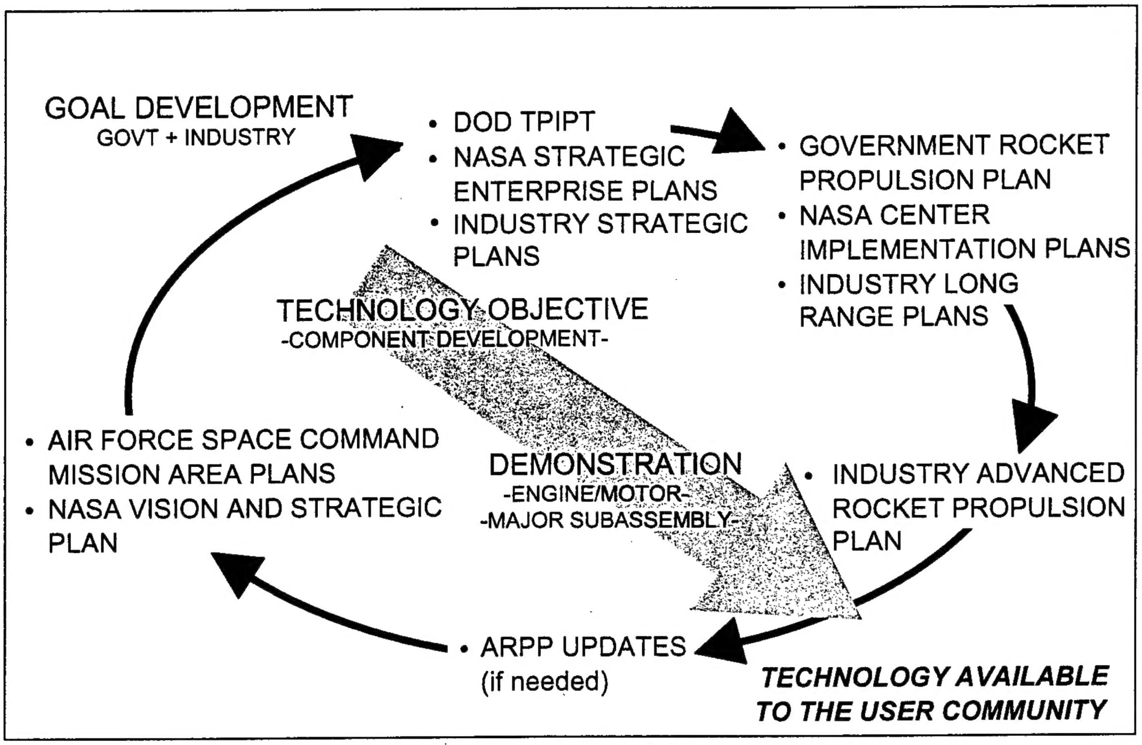


Figure 4. The IHPRPT Process Integrates With Major Planning Activity

Overlaid on this continuous planning process is the conduct of IHPRPT component technology programs and demonstrators. The success that each of these programs has towards meeting the goals outlined in the ARPP influences the planning process as well.

INDUSTRY PARTICIPATION

A cornerstone of the success of IHPRPT is its coordination with industry. The industry/government partnership that created and maintains IHPRPT requires that each partner actively participate. It has been noted that companies (and government agencies) all benefit from investment in IHPRPT commensurate with the effort expended on the program. The following are some of the key activities that industry should be doing to ensure the IHPRPT program's success.

PLANNING[iii]

All propulsion contractors participating in IHPRPT must have an approved ARPP. Specialty companies that do not work all aspects of a mission application area, but have valuable contributions to offer (e.g., a motor case or nozzle material researcher), must team with a propulsion company and participate in their ARPP. These ARPPs are the contractors' plans to meet the time-phased goals of each mission application area they are working in. A contractor need not work all three mission application areas but must work all applicable goals relating to a propulsion system class (this does not mean each component technology project must work all goals). The major aspects of an ARPP (in descending order of priority) are:

- Complete description of how meeting the goals will be demonstrated (including test method, data acquisition, data analysis , etc.)
- Company's long range business strategy to achieve these goals (e.g., make or buy)
- Plans for collaboration or teaming, as necessary, to meet all goals in the application areas being worked
- Complete description of the projects needed to develop the technology base that will be demonstrated
- Detailed roadmap showing the technology development/demonstration pathway
- Estimation of the funds required for each project
- List of milestones for each project (more than one/year for current or near-term projects)

- Full explanation of the technical challenges that must be overcome, and how that will be accomplished
- Critical path analysis with an explanation of the current status along that path
- Payoff analysis describing the system level payoffs expected by attainment of the technologies being demonstrated
- Identification of potential military, civil and commercial transition targets

The GRPP is a combination of industry ARPP inputs and government in-house technologies. It is the government's overarching plan designed to prioritize projects, to establish critical paths and to provide a logical set of tasks needed to achieve the goals with minimum risk.

STEERING COMMITTEE PARTICIPATION

Each company designates a primary IHPRPT representative that attends Steering Committee meetings, performs on action items, and organizes and coordinates briefings at the meeting and ARPP reviews. The Steering Committee meetings include an industry caucus/debrief session. Each company representative actively participates in the caucus to bring to light areas of concern as well as to point out areas where development is progressing well.

Traditionally, industry has sponsored the Summer Steering Committee meeting. This obligation is rotated between participating companies.

DEVELOPING TECHNOLOGY

IHPRPT was founded as a government/industry partnership and as such, industry has an obligation to fund technology development through IR&D. Figure 5 shows the split of DOD, NASA, and Industry funds. In order for funds to be counted as IHPRPT funds, they must be directed at IHPRPT goals and be included in the ARPP roadmap for a demonstrator.

In addition to allocating company resources to pursue IHPRPT goals, industry also conducts contracted technology programs. The government procures IHPRPT programs through various contractual instruments (Program Research and Development Announcement (PRDA), Broad Area Announcements (BAA), NASA Research

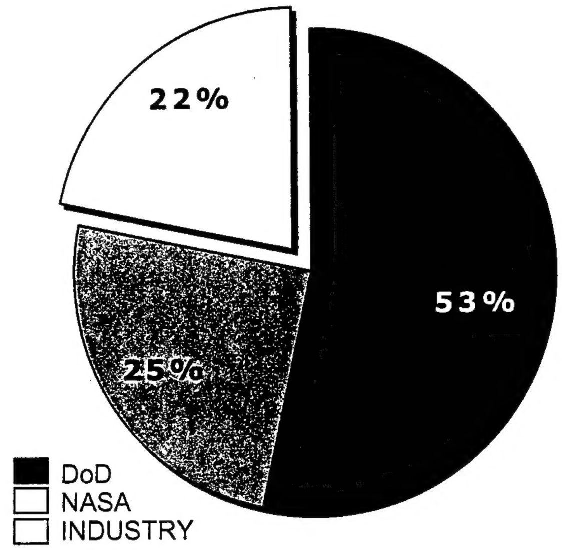


Figure 5. Funding Sources for IHPRPT

Announcements (NRA), and Requests for Proposal (RFP) to name a few). Companies respond with proposals. IHPRPT has been instrumental in implementing significant changes to the procurement process to streamline proposal evaluation and reduce cost to the contractors.

During the conduct of the IHPRPT technology programs, progress toward the technical objectives is constantly monitored. Meeting the IHPRPT technical objectives is an important measure of program success.

IDENTIFYING COMMERCIAL TRANSITION OPPORTUNITIES

Industry provides additional value to the program by identifying commercial launch vehicle transition opportunities. With the expansion of the commercial market and increased reliance on commercial vehicles for government payloads, synergy with commercial vehicles is essential to ensure high return on investment.

PROGRAM ADVOCACY

Advocacy for the IHPRPT program funding is a major function for industry (in addition to government efforts). With its logical structure, specific time-phased goals and several significant success stories, the IHPRPT program is usually well supported. Nevertheless, aggressive marketing of the payoffs associated with funding IHPRPT is required to ensure future resources are available.

TEAMING

Teaming between IHPRPT participants is highly encouraged by the government. There are several ways that industry should consider teaming:

- Team with another propulsion company: Teaming between propulsion companies leverages technology investment and can build complementary teams where each company conducts technology development in their area of strength. This is especially true on demonstrator projects where there is quite often only one demonstrator and it is unusual for one contractor to have all of the component technologies in hand to demonstrate the goals. Furthermore, involving more than one propulsion company also increases transition opportunity.
- Team with suppliers: Material and component suppliers often have the best understanding of improvements possible with their products. Bringing them onto a propulsion company team increases the chances for meeting the goals and for transitioning the technology.
- Team with government laboratory: Significant in-house research and development is conducted at the laboratories under IHPRPT and other funding. Government in-house work should be supported in company ARPPs. Teaming with government laboratories ensures that the technology development is considering transition of their technology to industry. Cooperative Research and Development Agreements (CRADAs), Space Act Agreements (with NASA), and Technology Investment Agreements (TIAs) are all vehicles with which to team with the government.

SOLID PROPULSION AND IHPRPT: A CASE STUDY

This portion of the paper examines how IHPRPT has been applied to Solid Propulsion for Boost. This study will first look briefly at why solid propulsion is a focus area for IHPRPT. Next, an overview of the goals and payoff of IHPRPT relative solids will be examined. Finally, a discussion of the Phase I Solid Boost Demonstrator, transition opportunities, and the value of IHPRPT to solids will be included.

PHYSICS FAVORS SOLIDS (FOR BOOST PROPULSION)

Solid propulsion is utilized on every operational U.S. launch system today. The only operational commercial launch vehicles utilize solid propulsion (Athena, Taurus, and Pegasus), as well. The world's only operational reusable launch vehicle derives approximately 80% of its takeoff thrust from solids. The extensive use of solid propulsion, especially for thrust augmentation, is not just an American phenomenon. French, Japanese, and Indian launch vehicles all use solids for thrust augmentation (bottom row).

Figure 6 shows a brief history of several vehicles that started out all liquids (top row) and added solid trust augmentation. The EELV was the most recent program to do this.

There are many reasons why solid propulsion is chosen: proven cost, reliability, and operability advantages[iv], but the significant level of energy density compared to other alternatives is one of the most important reasons. Figure 7 shows a comparison of the Isp*density for several different fuels (liquids and solids). This shows that the energy density of solids is significantly higher than liquid systems.

The rocket equation shown below contains terms to account for impulse, drag, and gravity.

$$\Delta V = gI_{sp}\ell n\left(\frac{m_o}{m_f}\right) - \int_o^{\tau}\frac{D}{m}dt - \int_o^{\tau} g\cos\theta$$

I_{sp} = specific impulse

m_o = initial mass

m_f = final mass

D = drag coefficient

θ = angle of attack from vertical

The terms drive selection of compact, high thrust systems (high energy density) to minimize drag and escape the earth's gravity. As Figure 7 shows, solid propulsion best fits that description.

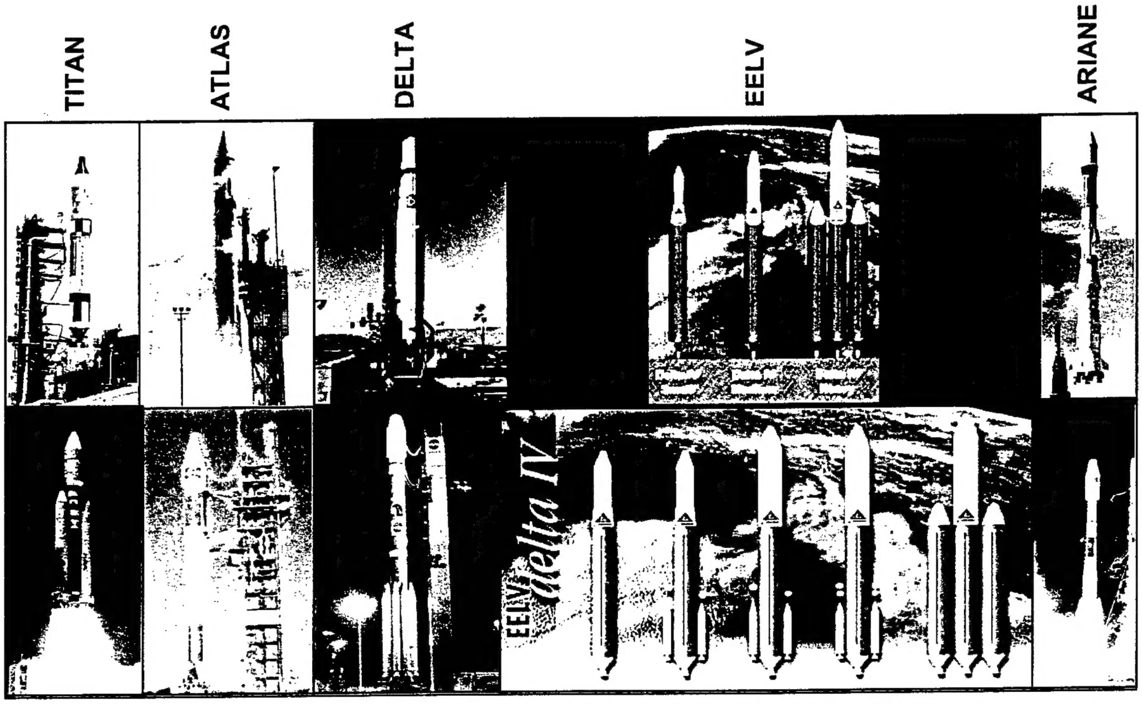


Figure 6. Launch Vehicles That Added Solid Thrust Augmentation

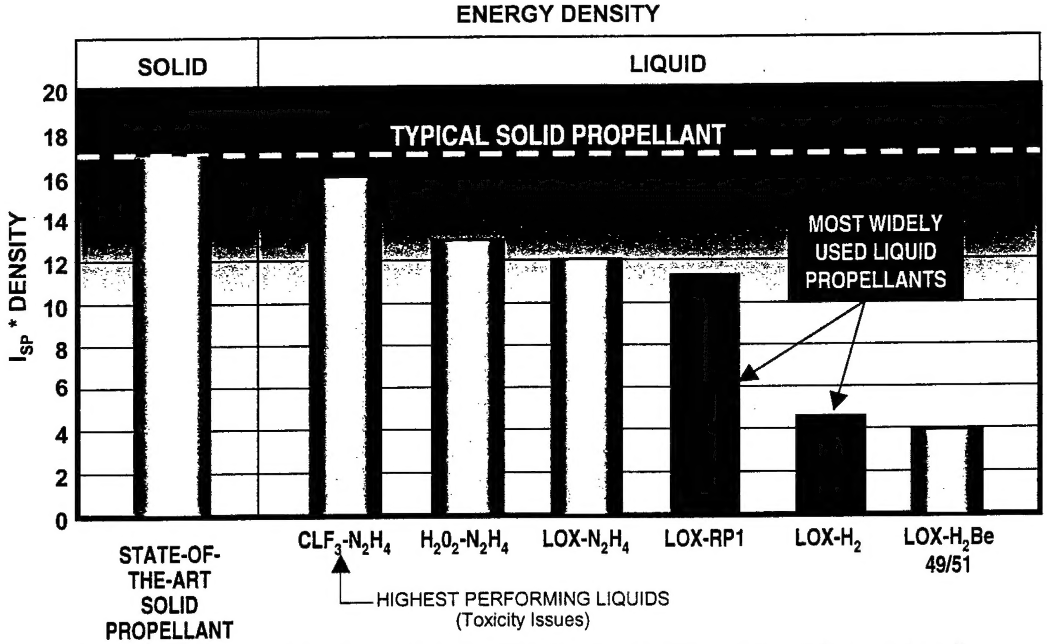


Figure 7. Energy Density of Various Propellants (Source: Rockwell International)

SOLID PROPULSION TECHNOLOGY GOALS AND PAYOFFS

The goals and payoffs for solid propulsion are shown in Tables 2 and 3, respectively. Simultaneous increases in performance and reductions in cost as well as increases in reliability lead to a much reduced cost per pound of payload to orbit.

The payoffs were calculated by inserting technologies to meet the goals into CASTOR 120® and Orbus 21 Motors in an Athena II launch vehicle. This vehicle has a CASTOR 120® first and second stage and an Orbus 21 third stage. The

Table 2. IHPRPT Solid Boost Goals

Goal	Phase I	Phase II	Phase III
Cost	-15%	-25%	-35%
Isp	2%	4%	8%
Mass Fraction	15%	25%	35%
Reliability	25%	50%	75%

Table 3. IHPRPT Solid Boost Payoffs

Payoff	Phase I	Phase II	Phase III
Cost	-15%	-25%	-35%
Payload Increase	28%	52%	93%
Cost/Lb to LEO	$3,555	$2,796	$2,047

assumed baseline cost was $25M and the payload capability to low Earth orbit was 5,000 per pound.

IHPRPT PHASE I SOLID BOOST DEMONSTRATOR

Thiokol Propulsion was selected in 1999 to fabricate and test the Phase I Solid Boost Demonstrator. The 92-inch-diameter, 30-foot-long motor with over 100,000 pounds of propellant will be tested in 2000. The test will demonstrate compliance with all Phase I Solid Boost goals.

Figure 8 is a cross section of the motor and shows generically that every component area will incorporate advanced technology to demonstrate the goals.

SOLID PROPULSION TRANSITION OPPORTUNITIES

There are numerous Solid propulsion transition opportunities available. Table 4 lists some of the possible systems that could incorporate IHPRPT Solid Propulsion technologies.

THE VALUE OF IHPRPT TO SOLID PROPULSION

The IHPRPT program is a major source of technology funding for the Solid Propulsion Industry. IHPRPT is providing focused technology improvements that will be major contributors to the future of space launch.

FUTURE IHPRPT FOCUS FOR SOLIDS

The future focus for IHPRPT solid propulsion technology will expand to address the critical issues of operability and reusability, as well.

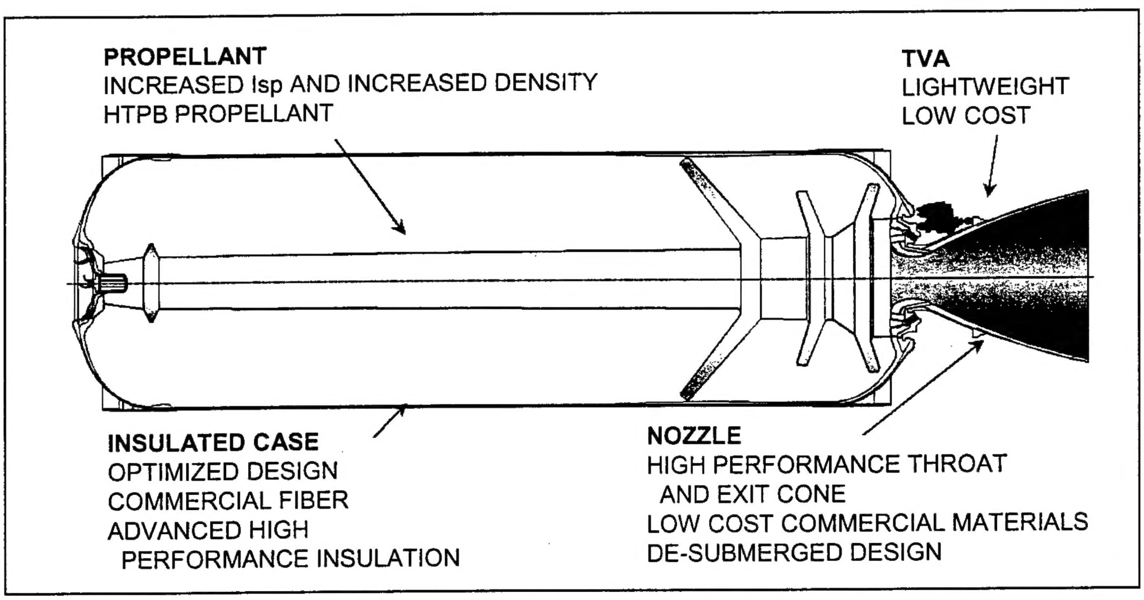
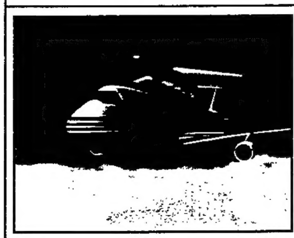
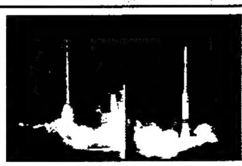
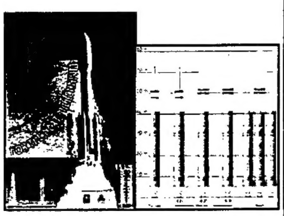


Figure 8. Phase I Solid Boost Demonstrator

Table 4. Solid Propulsion Space Launch Transition Opportunities

SYSTEM	TECHNOLOGY
 RSRM	• Lightweight Insulation • Low Cost/Weight Nozzle
  Athena 1 and 2/ Taurus/Air Launch	• Lightweight/Low Cost Insulated Case • Lightweight/Low Cost Nozzle • Lightweight/Low Cost TVA • Improved Propellant
 EELV (Atlas/Delta)[6]	• Lightweight/Low Cost Insulated Case • Lightweight/Low Cost Nozzle • Lightweight/Low Cost TVA • Improved Propellant • Lightweight Composite Attach

SUMMARY AND CONCLUSIONS

The IHPRPT program is a highly coordinated U.S. DOD/NASA and industry effort focusing technology to double rocket propulsion capability by 2010 for space and missile applications. The rigorous process is designed to be challenging for all participants, maximizing military, civil, and commercial rocket propulsion payoffs.

This model research and development program leverages technology investments from all the U.S. participants in advanced rocket propulsion. Goal-oriented, application focused and transition opportunity focused, the national technology program enabling new and low-cost space missions is IHPRPT.

Notes and References:

[i] The IHPRPT program also establishes goals for military propulsion improvement (strategic and tactical). Those improvements are outside the scope of this paper.

[ii] Summarized and excerpted from a draft copy of "Point Paper, Intergrated High Payoff Rocket Propulsion Technology," Dr. Robert C. Corely, Air Force Research Laboratory

[iii] Summarized and excerpted from a draft copy of "Point Paper, Intergrated High Payoff Rocket Propulsion Technology," Dr. Robert C. Corely, Air Force Research Laboratory

[iv] Alain Davenas, et.al., "Solid Propulsion for Space Applications: A Roadmap", presented at 51st IAF Congress, Rio De Janeiro, Brazil, October 2000